Simultaneous EEG/MEG and ECoG source characterization of interictal spikes

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1 Introduction

Interictal spikes observed in the EEG and MEG of Temporal Lobe Epilepsy (TLE) patients often show a complex spatio-temporal pattern (fig 1). This implies that a single stationary dipole model cannot characterize the sources. Also, in order to explain the high amplitudes, considerable amounts of cortical tissue must be assumed to be active[1].

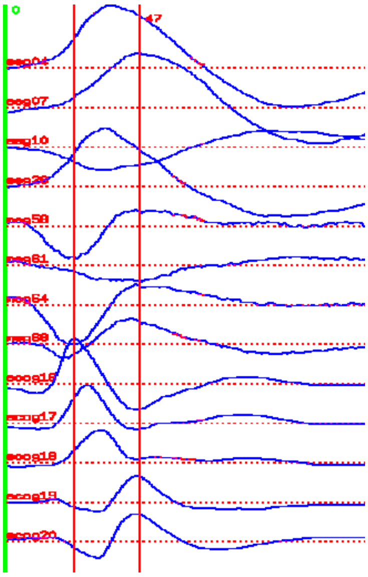

Figure 1: *EEG (top 4 rows), simultaneous MEG (middle 4 rows) and ECoG (bottom 5 rows) from a TLE interictal spike.*

For some TLE patients that do not respond the pharmacological treatment, epilepsy surgery is an option. In those cases, the determination of the location of the sources and the *sequence* in which they become active is of prime importance. In this paper, we investigate the interpretability and validity of dipole source localization based on EEG, MEG and simultaneous EEG+MEG for TLE interictal spikes.

Real validation can be attempted if epicorticograms (ECoG's) recorded prior to resection are available. It must be realized, however, that ECoG's are remote measurements as well, and that often they don't provide exact localization information either. Therefore we simulated ECoG's as well, in order to investigate whether they can be used to validate results obtained non-invasively.

Finally we looked at a set of real simultaneous EEG+MEG data from a patient of which an ECoG, recorded later, prior to surgery, was available as well.

2 Methods

We set up a double layer source configuration on two areas of a triangulation of the left temporal lobe (fig. 2). The areas were switched on in sequence and overlapped in time. From this a reference EEG (63 electrodes), MEG (151 axial gradiometers) and ECoG (20 electrodes) were computed by placing the source in a realistic volume conductor model. This model contained a skin- (1527 points, 0.33 S/m), a skull- (1425 points, 0.0168 S/m) and a brain- compartment (1505 points, 0.33 S/m).

Spatially correlated noise was generated by placing 2121 dipoles at random positions in the cortex in the same volume conductor model. The source strength functions of all of these dipoles were temporally uncorrelated. This noise was added to the simulated EEG and MEG and bandpass filtered between 0.7 and 70 Hz to mimic real measurements. This resulted in a SNR of 3.4 for the EEG and 1.5 for the MEG. When added to the ECoG the resulting SNR was 6.8.

A two stationary dipoles model was fitted to the EEG, the MEG and to the simultaneous EEG+MEG. Dipole positions and strengths were compared to the original distributed source configuration, and EEG, MEG en ECoG resulting from these dipole models were compared to the original reference simulations. For the EEG+MEG case, EEG and MEG were scaled to an equal RMS value.

Finally, real data measured from a TLE patient was treated. A simultaneous 32 channel EEG and 151 channel MEG, containing spikes originating from the left temporal lobe, was recorded. From the same patient an ECoG was available, measured prior to surgery using a regular 20 electrode grid over the exposed temporal lobe. Spikes observed in the ECoG were assumed to be generated by the same source

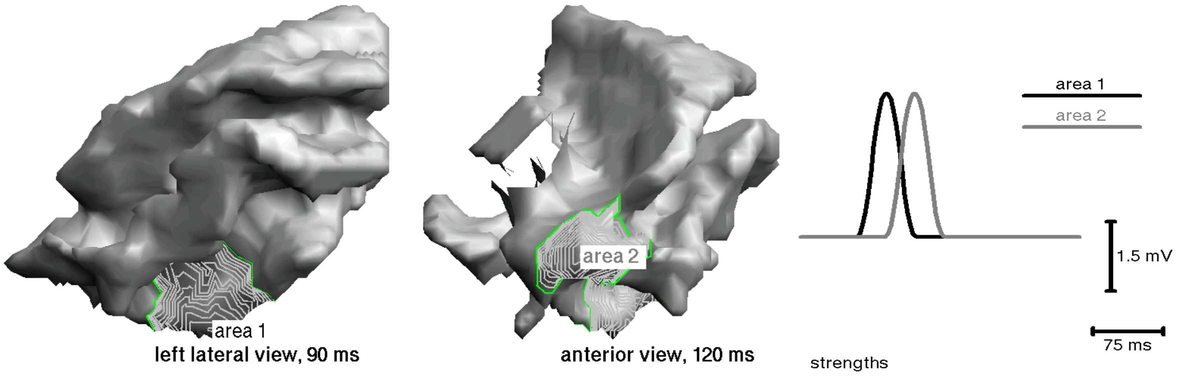

Figure 2: *Source distribution (left panels) and strength functions (right panel) used in the simulation.*

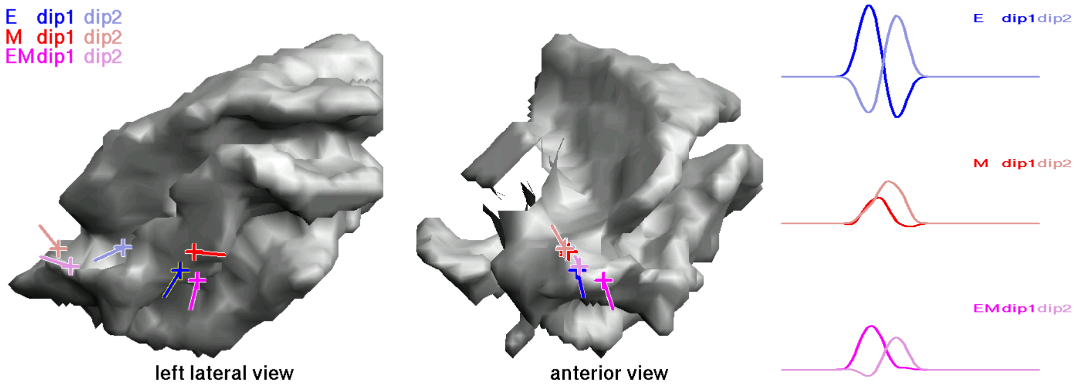

Figure 3: *Dipole positions (left panels) and strength functions (right panel) for the noiseless simulation. EEG is blue, MEG red, EEG+MEG magenta. The darker shades refer to dipole #1, the lighter ones to #2.*

as those in the EEG+MEG (fig. 1). Principle Component Analysis of this data showed that 2 spatio-temporally independent sources could represent the data. In addition to a two dipole solution, a minimum L^2 norm type distributed source inverse solution was tested here as well[2].

3 Results

3.1 Simulations without noise

In fig. 3 dipole positions and source strengths estimated on basis of the EEG (blue), MEG (red) and simultaneous EEG+MEG (magenta) for the noiseless simulation are shown. The darker shades represent the dipole that is active first, the lighter ones the second dipole. The simulated ECoG for these cases is shown in fig. 4. The regular grid displayed is overlying the temporal lobe, with electrode#16 in the lower left corner near the tip. Note that all dipole positions

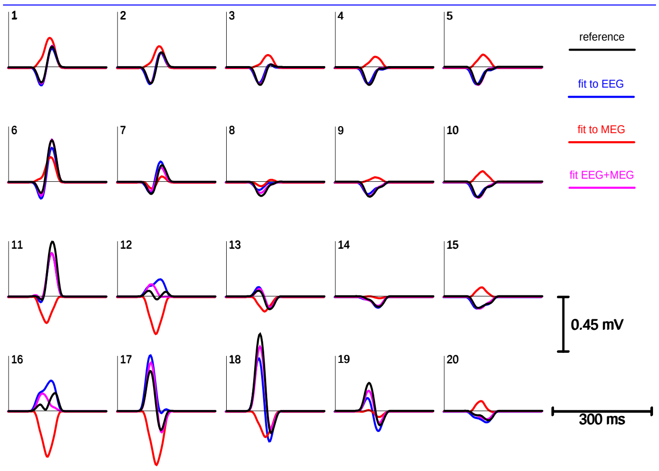

Figure 4: *Simulated ECoG's for estimated dipoles, noiseless case. The blue line is the EEG fitted signal, the red MEG fitted, magenta is MEG+EEG. The black line is the reference ECoG.*

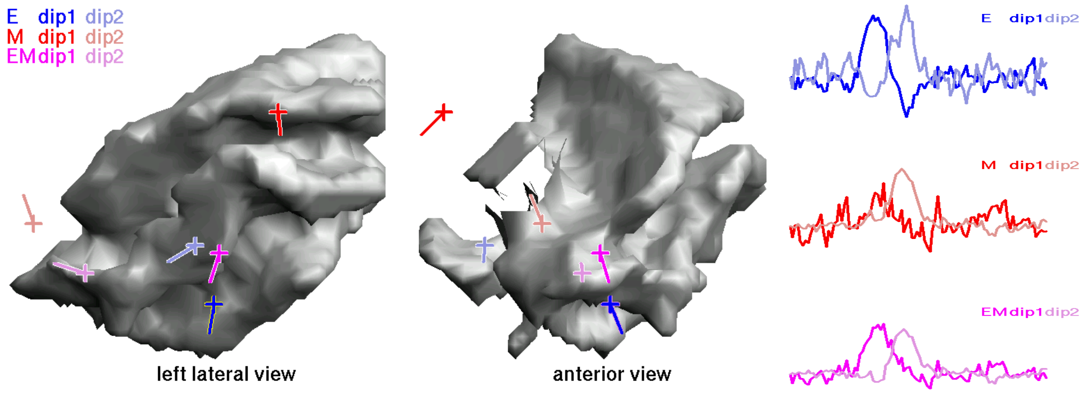

Figure 5: *Dipole positions (left panels) and strength functions (right panel) for the simulation with noise. Layout as in fig. 3*

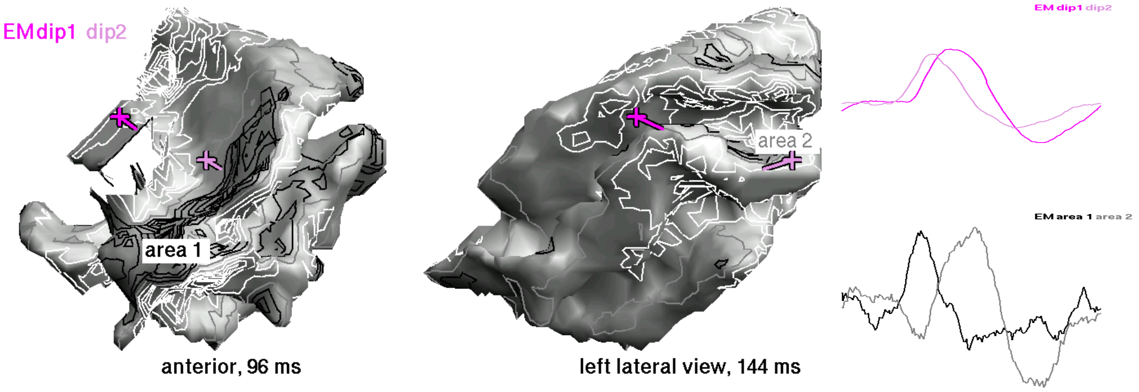

Figure 6: *Dipole positions and double layer distribution (left panels) and strength functions (right panel) for the real measurement. White isofunction lines represent an equivalent double layer strength of -0.2 mV.*

are acceptable, but that for the MEG the sequence of activation and simulated ECoG's are inaccurate. Results are are summarized in table 1.

3.2 Simulations with noise

Fig. 5 shows dipole positions and source strengths estimated on basis of the EEG (blue), MEG (red) and simultaneous EEG+MEG (magenta) for the simulation with noise added. Note that only EEG+MEG produces acceptable dipole positions, and that source strengths are similar to those in fig. 3. The simulated ECoG's are shown in fig. 7. Relative errors are summarized in table 2.

3.3 Real measurements

Fig. 6 shows dipole positions and source strengths estimated on basis of the simultaneous EEG+MEG (magenta) for the real measurement. Also shown are isofunction lines of equal double layer strength at two time instances for the distributed source inverse

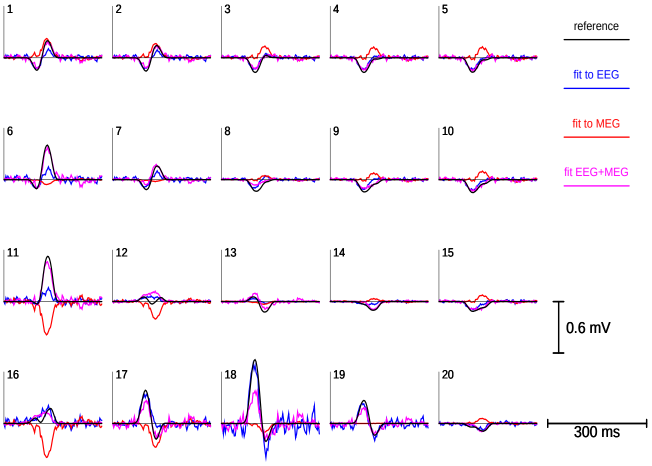

Figure 7: *Simulated ECoG's for estimated dipoles, with noise. Layout as in fig. 4.*

solution, and the double layer strength as estimated in two distinct areas. Note that a sequence of activation cannot be extracted from the dipole strengths, whereas for the double layer solution it can. The simulated and measured ECoG's are shown in fig. 8. Here waveshapes are slightly better reproduced by the double layer solution, *e.g.* in sensors 16 and 15. In table 3 both relative errors and correlation coefficients are given.

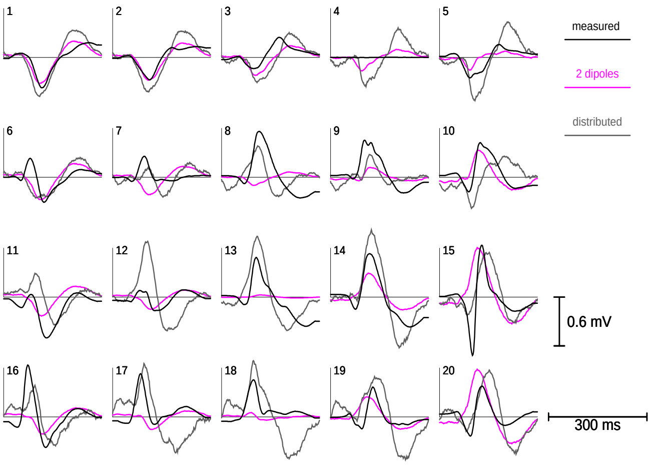

Figure 8: *Measured (black lines) and simulated ECoG's. Magenta lines represent the 2 dipole model, grey lines represent the distributed source solution.*

Table 1: *No noise, 2 stationary dipoles. Relative difference fitted – reference*

	EEG ref.	MEG ref.	ECoG ref.
EEG fit	0.065	0.325	0.479
MEG fit	1.50	0.040	1.39
E+M fit	0.105	0.078	0.276

Table 2: *Spatially correlated noise, 2 stationary dipoles. Relative difference fitted - reference*

	EEG ref.	MEG ref.	ECoG ref.
EEG fit	0.452	0.643	0.634
MEG fit	1.33	0.338	1.30
E+M fit	0.353	0.242	0.472

Table 3: *Real measurements, 2 dipoles and* **double layer**. *Relative difference and correlation coefficient*

	EEG	*(cc)*	MEG	*(cc)*	ECoG	*(cc)*
EEG	0.180	*0.98*	1.05	*0.29*	0.887	*0.46*
MEG	9.90	*-0.70*	0.584	*0.81*	79.6	*-0.22*
E+M	0.278	*0.96*	0.831	*0.58*	0.857	*0.52*
E+M	**0.390**	***0.92***	**0.418**	***0.91***	**1.23**	***0.59***

4 Discussion

When epilepsy surgery is considered, the localization and timing of the sources of an epileptic spike is important. If these sources are thought of as extended areas of cortical tissue that are simultaneously active, application of dipole models may not be valid.

Validation can be done when invasive measurements exist. ECoG's recorded during surgery are invasive measurements. However, these often don't provide readily interpretable localization information either. We therefore also tested whether an ECoG simulated on basis of sources computed from EEG, MEG and EEG+MEG data could be used for validation.

This study shows that, in a *noiseless* setting, when using dipoles to model an assumed distributed source, EEG, MEG and EEG+MEG perform equally well on localization. Localization is not in the center of the distributed source however. Source strengths show that EEG performs well on timing, EEG+MEG performs better and MEG does worse. This is reflected in the (lack of) agreement between simulated and reference ECoG's. For EEG and EEG+MEG, simulated and reference ECoG's are similar.

In a situation where *spatially correlated noise* is added it is shown that the localization performance of EEG and MEG alone deteriorates, and that EEG+MEG localization remains good. Timing properties don't change much. The ECoG simulated on basis of EEG+MEG is acceptable. For EEG alone, simulated and reference ECoG are still much more similar than in the case of MEG alone.

These results suggest that a good correspondence of the ECoG indicates that timing information is OK, but localization information is not necessarily accurate.

When applied to *real EEG+MEG measurements*, for the 2-dipole model simulated and reference ECoG don't correspond well. Timing as observed in the source strengths was ambiguous.

The distributed source model performs only marginally better.Timing as observed in the double layer strength in two distinct areas of the temporal lobe suggests that a distributed source model could do a good job here. However, results are not easily interpretable as far as localization is concerned. More constraints are needed in order to get a reliable, interpretable, distributed source inverse solution.

References

[1] J. Ebersole, "EEG source modeling. The last word", *Journal of Clinical Neurophysiology* **16**, 297–302, 1999.

[2] F. Greensite and G. Huiskamp, "Temporally unconstrained space-time treatment of linear formulations of the inverse problem of electroencephalography", *Annals of Biomedical Engineering* **28**, 1253–1268, 2000.